MODELING THREE-DIMENSIONAL WAVE PROPAGATION IN THE SAN FRANCISCO BAY AREA: ANNUAL PROJECT SUMMARY DECEMBER 20 2000.

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Investigations Undertaken

1. Modeling of Local Seismograms for Basin Structure

    I. Shallow velocity structure in the northern San Francisco bay, relative site effects at Treasure and Yerba Buena Islands

    II. 2D waveform modeling for shallow structure in Santa Clara Valley

2. Modeling of Teleseismic Waveforms for Basin Structure

    I. Differential traveltime and relative amplitude measurements of teleseismic P-waves in the Santa Clara Valley

    II. 3D finite difference modeling of the teleseismic wavefield, and simulation of relative amplification and traveltime residuals

    III. Spectral analysis of teleseismic P-waves and basin generated coda

3. Participation in Santa Clara Valley modeling workshop held at the Menlo Park USGS campus on October 24, 2000.

Results

Modeling of Local Seismograms for Basin Structure

We have completed a study of seismograms recorded at 6 strong motion sites located around the northern San Francisco Bay (Figure 1) for the August 18, 1999 Bolinas earthquake (M_L5.0; M_W4.8). This work involved forward modeling of complete transverse and radial component seismograms to a maximum frequency of 2 Hz to obtain constraints on the shallow velocity structure of the region. Examples of the transverse component modeling results are shown in Figure 1. Our modeling approach began with characterizing the best average 1D velocity structure. The San Rafael site, which is near the north-western edge of the basin along a path traversing Franciscan terrain geology indicated that the near-surface velocity gradient is less pronounced than in the 1D velocity model used to routinely estimate seismic moment tensors (e.g. Dreger and Romanowicz, 1994). Improved fits were obtained with a 3 km thick 2.4 km/s layer over a faster upper crust of 3.5 km/s, and this model is seen to perform well as the background rock structure at all of the stations studied. This interface produces a near-receiver multiple (a large amplitude secondary S phase) seen at the more distant stations (e.g. phase labeled C, Figure 1). To model the extended surface wave train observed at the Richmond (Figure 1) and Berkeley (not shown) sites an additional 200 m layer with a shear-wave velocity of 500-800 m/s representing weathered rock and alluvium is required. The waveforms at Treasure Island (TI) are considerably more complicated and require the consideration of a thin surficial layer of slow velocity bay mud to produce the extended surface wave train. Bay mud along this path is reported to be approximately 100m thick and shear-wave velocities ranging from 150-500 m/s were tested. The best 2D model has the mud layer beginning at the western margin of the bay extending eastward to TI and pinching out at Yerba Buena Island (YBI). Modeling of data from the down-hole Geotechnical Array at TI provides further validation of the shallow velocity structure we obtained (Figure 2). Our modeling has revealed that the complexity observed at TI and YBI is due to shallow structure and depends on the placement of the Franciscan Terrain bedrock ridge at the YBI site. The extended surface waves observed at TI are confined to the shallowest mud layer and propagate horizontally to the site indicating that the standard approach of simulating surface records by vertical propagation of down-hole rock motions is not applicable. The results of this analysis demonstrate that a minimum shear wave velocity of 400 m/s and short wavelength structure in the upper 100-200m is needed to explain observations at some sites to a maximum frequency of 2 Hz. It will be necessary to consider such low velocities and short wavelength structure in earthquake scenario simulations. A manuscript describing this modeling is in preparation.

As described in our previous report we have completed simulations of local earthquakes recorded by the Santa Clara Valley Seismic Experiment array (SCVSE) using the 3D velocity model we developed during a previous phase of this project (e.g. Stidham et al., 1999), and the version 1 velocity model of the USGS (e.g. Brocher et al., 1997). We are presently performing simulations using the revised USGS 3D velocity model (Bob Jachens, written communication, 2000). These simulations are being compared to waveform and peak amplitude data, and a manuscript describing the simulation results is in preparation.

Modeling of Teleseismic Waveforms for Basin Structure

We have analyzed waveform data from 17 M_W>6.4 global earthquakes recorded by the SCVSE (Table 1). Of these we have identified 8 events (Figure 3a) with high signal to noise levels, which we have studied in terms of differential traveltimes and relative amplification of the primary P-wave arrival. Figure 3b compares the observed differential traveltime and relative amplification for an event located in South America. The signature of the deep basins is obvious in the measured parameters.

We have simulated P-waveforms for the 8 teleseisms using both the UCB (e.g. Stidham et al., 1999) and the USGS version 2 velocity models (Bob Jachens, written communication, 2000). These simulations were performed using the E3D finite difference (Larsen and Schultz, 1995) code by specifying a P plane wave with the appropriate azimuth and angle of incidence. The finite difference method is used to determine traveltimes, amplitudes and to simulate observed basin generated coda.

Waveform cross-correlation is used to obtain differential P-wave arrival times across the SCVSE relative to a reference station. The PG2 (situated over a bedrock ridge) and MHC (BDSN hard rock site) stations were used as reference each producing nearly identical results. Amplitude ratios relative to the same reference sites are measured in the 0.1 to 1.0 Hz passband. Figure 3c compares the observed and simulated amplitude ratios and traveltime residuals along a profile, which includes the northern third of the SCVSE array. The shear-wave structure for the UCB and USGS version 2 models are compared in Figure 3d. Because of computational constraints we limited the minimum shear-wave velocity of the USGS model to 1 km/s. The observed amplitude ratios and differential traveltimes show a sinusoidal pattern that is consistent with two deep sedimentary basins separated by a bedrock ridge. The estimated amplitude ratios and differential traveltimes show a similar sinusoidal pattern, however the magnitude of the anomalies is substantially different for the two velocity models. Both models have comparable maximum basin depth, however the velocity gradients in the USGS model generally result in higher velocity at a given depth. This is much more evident in the middle and southern profiles. In the example shown the UCB model fits the observations better over the western basin, and both models under predict the single observation over the eastern basin. However, the middle and southern profiles indicate that the UCB model over predicts the amplitudes and that the gradient structure used in the USGS model may be more appropriate. The UCB model better matches the large swings in the differential traveltimes. We are in the process of compiling the amplitude ratio and traveltime residual comparisons for the 7 other events to see if there are any systematic anomalies, which can aid in constraining the basin structure. In addition, since bedrock structure in the USGS model is based on independent subsurface and gravity data, we are planning to perform a number of simulations in which the structure is kept fixed but the velocity gradients within the basins are varied to attempt to better model the seismic observations.

The teleseismic data also displays upwards of 120s of coda, which is interpreted as surface waves from P-SV conversion at the bedrock interface. These basin-generated waves are either suppressed or not present at sites located over the bedrock ridge, but are very strong at sites over the deep basins. We are in the process of investigating the spectral characteristics of the P-wave coda, and have found pronounced peaks indicative of basin resonance modes.

References

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Non-Technical Summary

The focus of this project is to test compiled 3D Earth structure models in the prediction of earthquake ground shaking patterns. Additionally, this project investigates the variability in estimated ground shaking due to assumptions made in the construction of the 3D structure models and in terms of input earthquake source models. The results of this study will be useful in the development of methodology to predict ground-shaking patterns for future earthquakes.

Bibliography of Publications (March 1999 – December 2000) Resulting from this Contract

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Data Availability

Data and modeling results of this project may be acquired by contacting the PI, Douglas Dreger (dreger@seismo.berkeley.edu).

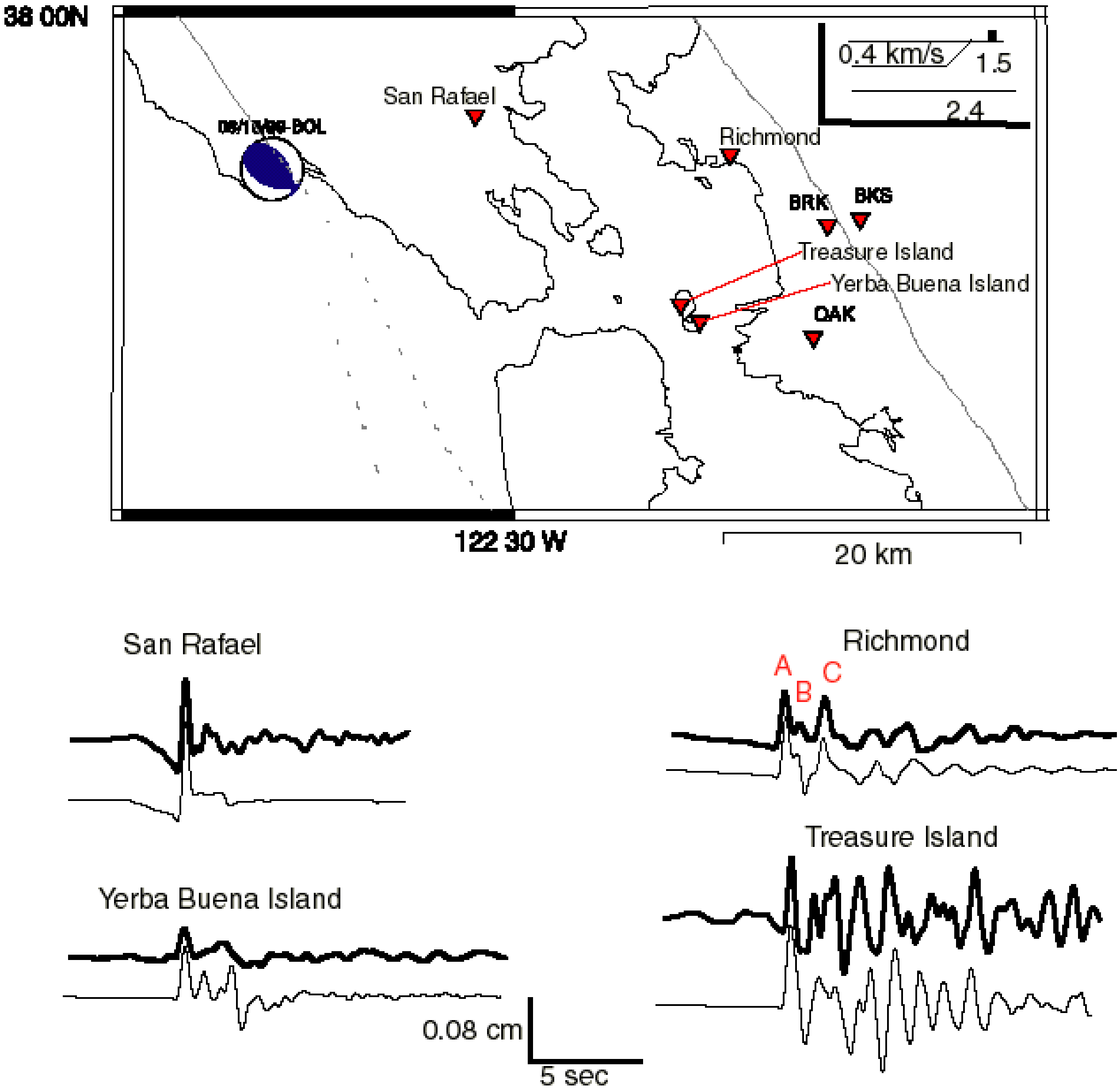

Figure 1. Observed transverse component displacement seismograms for the August 18, 1999 M_L 5.0 Bolinas earthquake (bold) are compared to synthetic seismograms. Both the data and synthetics were bandpass filtered between 0.02 to 2.0 Hz. The San Rafael site is modeled with a hard rock structure, while the Richmond site requires 200m of weathered rock and alluvium (500-800 m/s) to produce the observed surface waves. The extended surface wave train observed at Treasure Island (TI) requires an additional 100m mud layer (400 m/s). 2D structure was developed to model the transition from sediments at TI to Franciscan rock outcrop at Yerba Buena Island (YBI). The inset shows the 2D structure (not drawn to scale). This model consists of a 100m mud/alluvium layer (400 m/s) over 700m of weathered rock/alluvium (1.5 km/s). The shear wave velocity increases to 3.5 km/s at 3 km depth.

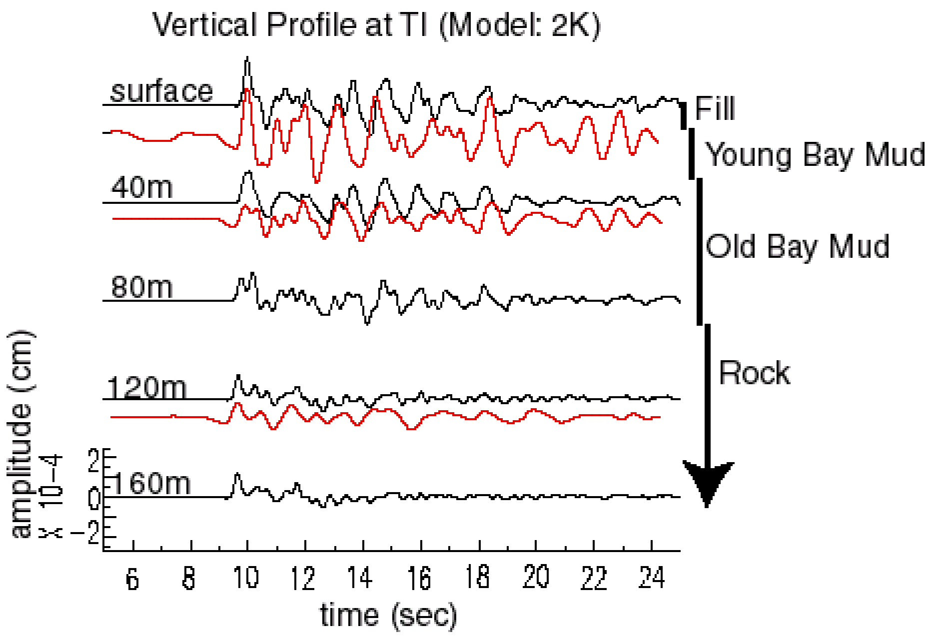

Figure 2. Transverse component displacement data recorded at the Treasure Island Geotechnical Array (red) is compared to 2D finite difference synthetic seismograms. The surface waves observed at stations above the rock-mud interface are propagating laterally into the site.

Table 1 – Teleseismic Events Recorded by SCVSE

Date	Origin Time	Latitude	Longitude	Depth (km)	Magnitude
*07/09/98	14:45:39.98	-30.487	-178.994	129.5	6.9
*07/16/98	11:56:36.42	-11.04	166.16	110.2	7.1
07/17/98	08:49:13.28	-2.961	141.926	10.0	7.1
*07/29/98	07:14:24.08	-32.312	-71.286	51.1	6.5
07/29/98	18:00:29.99	-2.693	138.901	33.0	6.6
*08/04/98	18:59:20.10	-0.593	-80.393	33.0	7.1
*08/20/98	06:40:55.82	28.932	139.329	440.5	7.0
*08/23/98	13:57:15.38	11.663	-88.038	54.6	6.7
09/02/98	08:37:29.91	5.41	126.764	50.0	6.8
*09/03/98	17:37:58.24	-29.45	-71.715	27.0	6.5
*09/21/98	12:09:39.66	-13.573	166.791	33.0	6.4
09/28/98	13:34:30.49	-8.194	112.413	151.6	6.5
10/28/98	16:25:03.84	0.839	125.966	33.0	6.6
11/08/98	07:25:48.51	-9.135	121.421	33.0	6.4
11/09/98	05:30:14.40	-6.954	129.022	33.0	6.7
11/09/98	05:38:44.22	-6.92	128.946	33.0	7.0
11/19/98	15:39:19.10	22.605	125.783	10.0	6.4

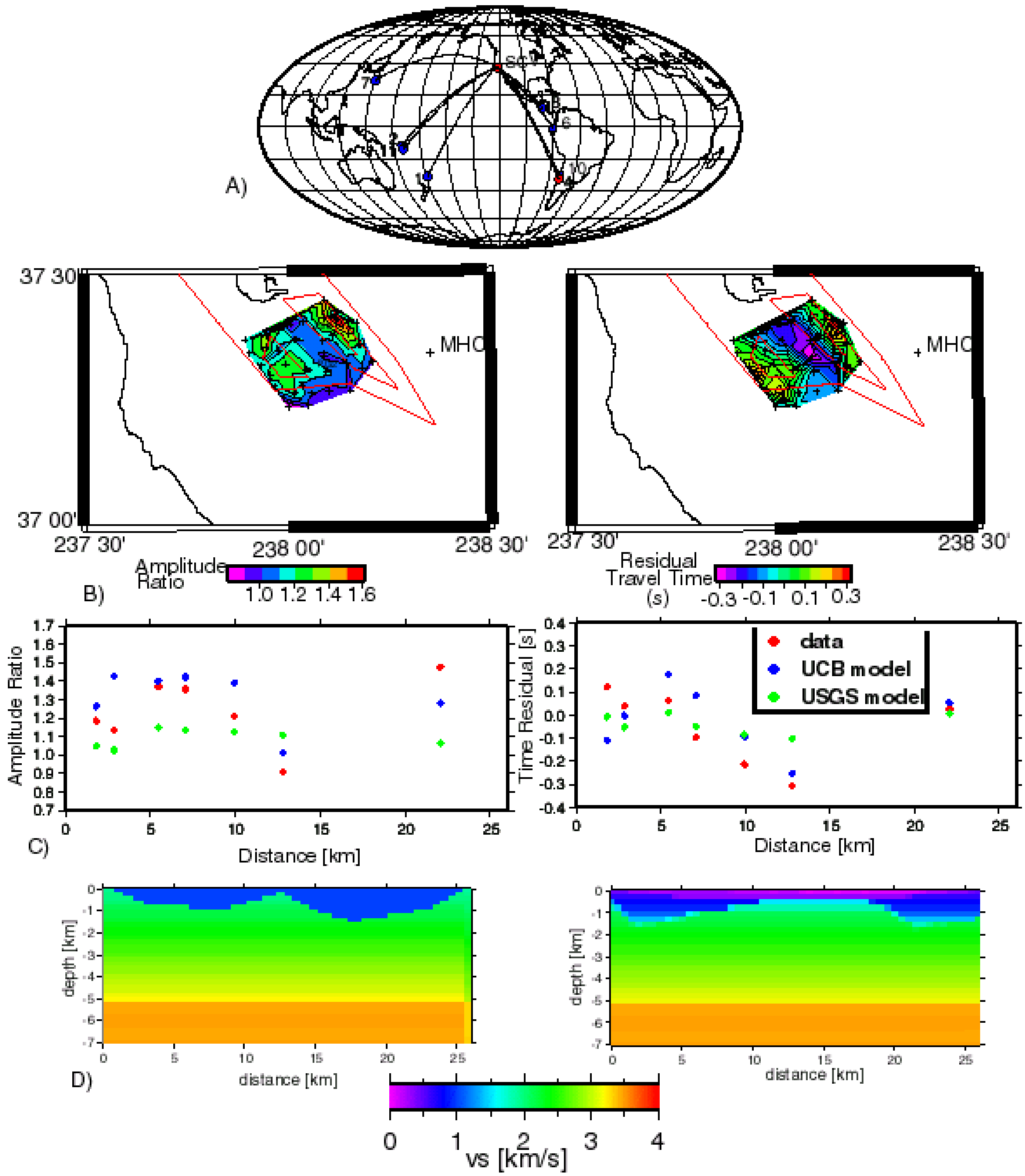

Figure 3. A) Map showing the locations of teleseisms that had usable P-waveforms. B) Contour maps showing observed relative amplitude ratios and differential traveltimes for an event located in South America. The Plusses show the locations of SCVSE instruments. C) Profile of observed and simulated amplitude ratios (left) and differential traveltimes (right) for the northern third of the SCVSE array. D) Comparison of S-wave velocity structure for the UCB model (left) and USGS version 2 model (right) for a cross-section through the northern third of the SCVSE array.